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Mortality Composting

A Review of the Use of Composting for the Disposal of Dead Animals

Victoria
The Place To Be

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Table of Contents

Executive Summary

Recent high-profile disease outbreaks in the United Kingdom (UK), North America and Australia have focussed the attention of biosecurity agencies on finding alternatives to rendering, on-farm burial, sanitary landfilling and pyre burning for carcass disposal in future outbreaks of emergency animal diseases. Composting of farm animal mortalities is one possible alternative as it appears to meet the biosecurity, environmental, and public health objectives of safe carcass disposal.

It is a relatively simple and effective process for the routine disposal of farm animal mortalities of all sizes (i.e. from poultry to mature cattle). It has attracted increasing interest due to a general contraction in the availability of rendering services and tightening of regulations governing on-farm burial. Even though it has the in-principle support of industry, environmental protection and biosecurity agencies in each state, indications are that it is not yet a widely adopted practice in Australia.

Mortality composting is particularly suited to the broiler industry for both routine and emergency management of mortalities for the following reasons:

- the availability on-farm of co-composting materials in the form of poultry litter

- on its own, or in combination with dead birds, poultry litter is an ideal substrate for composting. High temperatures are readily achieved in poultry litter piles without the need for high levels of management

- compared to larger animals, birds break down very quickly (10–14 days as opposed to many months for cattle)

In the case of an outbreak of an emergency animal disease (EAD), composting can be conducted effectively inside the poultry shed. This has the advantage of containing and limiting the spread of the outbreak.

An extensive search of the literature and consultations with both Australian and international experts identified many extension publications but no published standard operating procedures (SOPs) on mortality composting[1]. This is likely to be a major impediment to the use of on-farm composting in any future EAD outbreak.

The study identified several publications that would assist the drafting of SOPs, but it has also shown that further work is needed to fully evaluate the biosecurity of mortality composting, particularly in the context of an EAD outbreak. Thus SOPs must be underpinned by sound science.

Most of the available literature on mortality composting has concentrated on the general principles and operation of the process. Though the use of composting to manage mass mortalities shows great promise, the relative paucity of peer-reviewed science in this field needs to be addressed.

Very few studies have examined the biosecurity and environmental impacts of composting, either for routine management of dead animals, or for mass mortalities.

To the author's knowledge, a risk assessment of mortality composting has not yet been published, nor are any such studies currently under-way. Modelling techniques could be used to quantify the risks to animal and public health from the spread of particular diseases from mortality composting operations.

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[1] A draft document on mass poultry mortality composting has been developed by NSW DPI.

The inactivation of pathogens has been extensively studied in conventional composting systems. Pathogen inactivation studies are also needed in mortality composting systems. As temperature is the most important mechanism of pathogen inactivation in composting, such studies need to include an analysis of the spatial and temporal changes in temperature profiles within a heap.

The demonstration of in-shed composting is a critical part of any plan to prepare industry for an emergency disease outbreak like Avian Influenza (AI). This was also the experience of those involved in AI outbreaks in North America. Hands-on experience is important to ensure that SOPs can be effectively implemented in the event of an emergency, as the logistics of carcass disposal are a critical ingredient for success.

Biosecurity agencies in Australia, New Zealand, USA and Canada agreed to promote more widespread use of on-farm composting of dead stock so that it could become a realistic option to use in the event of an EAD outbreak. To facilitate more widespread adoption of mortality composting, it is critical to investigate mortality disposal in Australia, and identify drivers for change and barriers to adoption. This approach needs to consider the whole business context in key industries because the barriers to adoption of mortality composting may come from both internal (e.g. lack of awareness or cost) and external sources (e.g. local government planning permits).

The following recommendations have emerged as a result of this literature review:

- effective and targeted strategies must be developed to overcome the barriers to adoption of mortality composting. These strategies need to be underpinned by a sound understanding of the drivers and capacity for change in key intensive animals industries

- the implications of the use of mortality composting on biosecurity need further investigation. Pathogen inactivation and risk assessment modelling studies are required to identify critical pathways for the spread of pathogens, quantify risks and to assist in the development of SOPs

- studies are needed on the environmental impact of mortality composting. Perception about the negative environmental impact of mortality composting may limit its widespread adoption

- SOPs need to be developed for mortality composting, especially in the context of emergency carcass disposal. These procedures need to be demonstrated to industry

- an investigation is needed on the use of composting to manage an EAD outbreak in the Australian poultry industry. The investigation should consider the economic, technical and logistical feasibility of the use of composting. Various approaches to composting need to be evaluated from biosecurity, public health and environmental perspectives

1. Introduction

Rendering and on-farm burial are the predominant methods used by farmers for the routine disposal of domesticated farm animals. However, throughout Australia and in other developed countries, knackery and rendering services have been contracting and many farmers are seeking alternative stock disposal options. In Gippsland, for example, where several knackeries have closed in recent years, the illegal dumping of dairy cattle in waterways is now becoming a serious problem (W. Bath, EPA Victoria, pers. comm. 2005). Bonhotal *et al.* (2002) reported that the improper disposal of dead stock in New York State and Pennsylvania was becoming more widespread as farmers no longer had access to affordable rendering services. Dumping of stock is not only a risk to water quality but is also a biosecurity hazard and the source of many complaints to environment protection agencies from neighbours and downstream users.

On-farm burial is one of the simplest and most cost-effective methods of carcass disposal, but this too is becoming restricted as environment protection agencies seek to protect water resources from contamination. It has effectively been eliminated as an option for mass disposal in Virginia following the unearthing of intact 15 year old AI-affected poultry carcasses at a trench burial site in the late 1990s (Malone 2005). On-farm burial is also not possible in many irrigated areas in Victoria, where the watertable is within 2 m of the surface or where surface waters are within 100 m of the disposal site (EPA 1999a). New EPA licence requirements for aquaculture farms in Victoria could be a pointer to a general tightening of regulations governing on-farm burial of dead stock. These new licence requirements will be that fish waste is either disposed of to an approved site (e.g. rendering facility) or composted on the farm (S. Lee, EPA Victoria, pers. comm. 2005).

Recent high-profile mass mortality events in the UK, North America and Australia have focussed the attention of biosecurity agencies on finding alternatives to rendering, on-farm burial, sanitary landfilling and pyre burning for carcass disposal in future EAD outbreaks. Changes in environmental legislation and adverse public reaction greatly increased the logistical problems of carcass handling, transport and disposal during the UK Foot and Mouth Disease (FMD) outbreak of 2001. Licensed landfill sites could have easily disposed of all the stock slaughtered in this outbreak if it wasn't for the opposition of the local public, local authorities, politicians, pressure groups and farmers near the sites (Hickman and Hughes 2002).

There is a general commitment amongst biosecurity agencies in Australia, New Zealand, USA and Canada to promote more widespread use of on-farm composting of dead stock so that it could be used more effectively to manage future EAD outbreaks (DAFF 2005).

2. Study objectives

Biosecurity Victoria commissioned this study to investigate composting as an alternative method for the disposal of domesticated farm animals. The project had the following objectives:

- to review the current state of knowledge with respect to the composting of domesticated farm animals

- to identify the existence of any published SOPs for composting of domesticated farm animals
- to document experiences gained from the use of composting in EAD outbreaks in other countries, particularly with respect to AI and FMD
- to recommend research and development, extension and training strategies for addressing the most promising opportunities for using composting in domesticated farm animal disposal in Victoria

To address these objectives, a desktop review was conducted using the scientific literature (refereed journal articles, conference proceedings and scientific reports), extension publications and guidelines (e.g. fact sheets, training materials, SOPs), the Internet and email and phone consultations with Australian and international experts.

3. The composting process

Composting is a natural biological decomposition process that takes place in the presence of oxygen (air). In conventional composting systems, raw materials are mixed together to form a pile of relatively uniform nutrient content, particle size, porosity and moisture content. Mesophilic microorganisms first use the readily degradable substrates such as sugars, starch and proteins, and provided that the pile is of sufficient volume (usually >1m^3), temperatures rise rapidly. The materials may be turned every few days to move the outside layers into the centre of the pile, and to allow air to move more freely into the pile. In other systems, air is forced into the pile by a thermostatically controlled fan.

This first stage of composting (6–12 weeks duration) is characterised by high temperatures and rapid rates of decomposition and is usually termed the thermophilic stage or period of 'intensive decomposition' (Fig. 1). These conditions result in the elimination of nuisance odours and destruction of pathogens and weed seeds. It is during this stage that substrates such as fats, hemicellulose and cellulose are degraded.

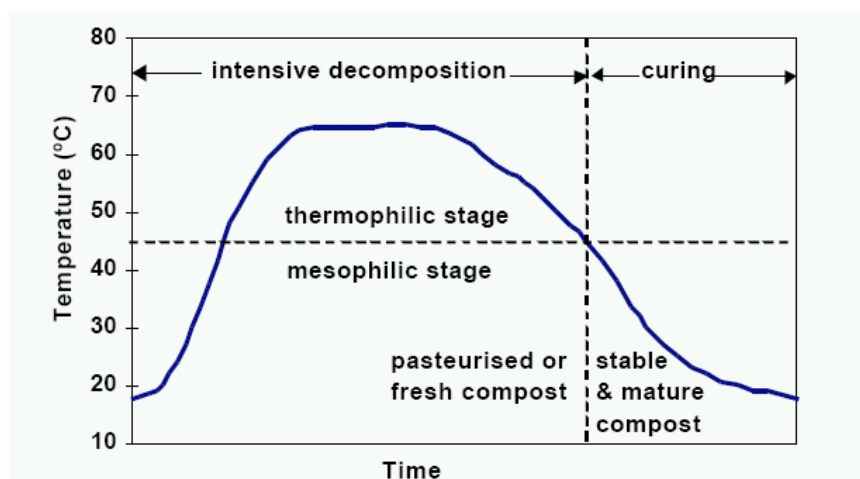Figure 1: Temperature development and stages of composting (Wilkinson *et al.* 2003).

As the composting process proceeds, and the availability of substrate becomes more limiting, temperatures begin to fall. This second stage of composting (lasting for 4+ weeks), called the maturation or curing phase, takes place under mesophilic conditions (under 45°C) and is characterised by lower rates of biological

decomposition under which aeration is no longer a limiting factor (Fig. 1). During this stage, the biologically resistant substrates such as lignocellulose and lignin are degraded. The maturation phase of composting has a large bearing on the suitability of the end product for a particular use.

Many reviewers have defined various optima for the composting process, including a carbon to nitrogen ratio (C:N) of between 25:1 and 30:1, moisture content within the range of 50–60% (w/w), porosity of 35–45% and oxygen levels of >10% by volume (Table 1). But these optima were developed for relatively homogenous organic materials such as manures, green waste, food wastes and biosolids and have questionable relevance to mortality composting.

Table 1: Desirable characteristics for composting (modified from NRAES 1992; Wilkinson *et al.* 2001; Keener *et al.* 2006).

Characteristic	Optimum	Reasonable range
Carbon to nitrogen ratio (C:N)	25–30:1	20–40:1
Moisture content	50–60% (wet basis)	40–60% (wet basis)
Porosity	35–45%	30–50%
Oxygen concentration	>10%	>5%
Bulk density		<640 kg/m^3
pH	6.5–8.0	5.5–9.0

4. Overview of mortality composting

A livestock mortality composting pile is a heterogenous mixture, so strict application of the principles discussed above is not possible. A mortality compost pile may contain an animal of large mass, having a high moisture content, low C:N ratio and nearly zero porosity, surrounded by a material (the carbon source) with a high C:N ratio, moderate moisture level and good porosity (Keener and Ellwell 2006). Kalbasi *et al.* (2005) aptly described mortality composting as the above ground burial of dead animals in a mound of supplemental carbon such as sawdust, litter, straw or wood shavings. Sufficient supplemental carbon is required around the carcass to absorb bodily fluids and to prevent odours from escaping from the pile.

According to Keener and Ellwell (2006), the decomposition process is anaerobic in and around the animal carcass, but as gasses are produced and diffuse away from the carcass, they enter an aerobic zone where they are degraded to CO_2 and water. Thus the surrounding material acts as a biofilter.

Mortality composting is generally conducted in 3 stages. In the primary stage of composting, the pile is left undisturbed as soft tissue decomposes and bones partially soften. The compost is usually then moved, turned or mixed to begin the secondary stage, during which time the remaining materials (mainly bones) break down further. Following completion of the secondary phase, the composting process is completed during a curing or storage phase.

Some bones of large mature animals may remain after completion of the secondary and/or storage stages of composting, but these are usually quite brittle and pose no health risk and will not damage farm equipment when applied to land (Mukhtar *et al.* 2003; Keener and Ellwell 2006). Nevertheless, Murphy *et al.* (2004) observed that the moisture content of a composting pile has a major bearing on the rate of decomposition of bones from cattle mortalities. If the pile is allowed to dry out, bones become very hard and appear to cease decomposition. Continued decomposition of the bones is achieved by wetting the pile on a monthly schedule for a period of about 6–9 months.

The time to completion of composting varies with the size of the animal, the compost formulation (e.g. type of carbon (C) sources used) and the management of the pile (e.g. mixing, turning and watering). As a general rule, the first stage of composting is complete in 7–10 days for small animals such as poultry, about 90 days for medium sized animals such as pigs and over 6 months for large carcasses (Mukhtar *et al.* 2004).

5. Practice of mortality composting in Australia

Mortality composting is likely to be affected by differing local government, environmental protection and public health legislation in each state. Environment protection agencies in Australia generally encourage on-farm composting of mortalities provided that the appropriate steps are taken to protect ground and surface waters from contamination and odours are controlled. This is consistent with the application of the waste management hierarchy of: avoidance, reuse, recycling, energy recovery, treatment, containment and disposal. This hierarchy underpins government policy with respect to waste management in each of the Australian states and in most developed countries.

Little information is available about the extent of the practice in Victoria and Australia. Nevertheless, mortality composting is briefly mentioned in many industry guidelines or codes of practice such as:

- AUSVETPLAN (AHA 2005)
- National Beef Cattle Feedlot Environmental Code of Practice (MLA 2000)
- National Biosecurity Manual—Meat Chicken Farming (Anon. 2003)
- National EMS for the Chicken Meat Industry (RIRDC 2003)
- Victorian Code for Broiler Farms (SOV 2001)
- Victorian Chicken Care Manual (VFF 2005)

In 1999, about 2,394 t (or 68%) of chicken carcasses from grower and breeder farms in South Australia were apparently recycled into compost, with the remainder disposed of in on-farm pits or trenches (EPA 1999b). The most common composting system used in South Australia at time of the EPA study was the rotary composter. Rotary composters are described below in Section 6.1.

A study of waste management practices in the chicken industry located on Victoria's Mornington Peninsula was also conducted recently (Stevens 2003). Of more than 106 poultry farms on the peninsula, about 'half a dozen' were reported to compost dead chickens on their farms. The most common practice was to dispose of dead chickens

in sanitary landfills. Proximity to residential areas was found to be the main reason why chicken farmers on the Mornington Peninsula did not practice composting.

Local government is frequently the responsible authority for intensive animal industries and may dictate carcass disposal options through planning and licensing conditions. In Victoria, Councils may ask the EPA to provide comments on an application but they are not obliged to adopt them. The EPA usually recommends an environmental management plan that includes details of dead stock management and a contingency plan for mass mortalities (J. Price, EPA Victoria, pers. comm. 2006). The Victorian Civil and Administrative Tribunal (VCAT) has also set planning conditions on dead stock disposal.

6. Mortality composting system design and layout

6.1. Main systems

Mortality composting began in the poultry industry in the USA in the early 1980s and soon spread to other industries and has also been used for road kill. In the past, specific recommendations were made for composting different animal species, but this failed to recognise the similarities in each process (Keener *et al.* 2000). The basic forms of mortality composting are conducted either in bins or piles/windrows[2].

Bin composting is usually conducted in a three-sided enclosure on a hard stand (e.g. concrete or compacted soil). It may or may not be covered by a roof, though a roof is usually required in high rainfall areas. Designs are available on-line for purpose-built constructions with concrete floors, roofs and wood or concrete side-walls (NRCS 1994; Fig. 2). In its simplest form, the walls can be constructed of hay bales or any such material that can adequately confine the composting pile (Mukhtar *et al.* 2003). Simple bins can also be constructed from pallets or wood and plastic mesh. These are sometimes termed 'mini-composters' and are suitable for small animals such as poultry, rabbits, piglets and fish (Brodie and Carr 1997).

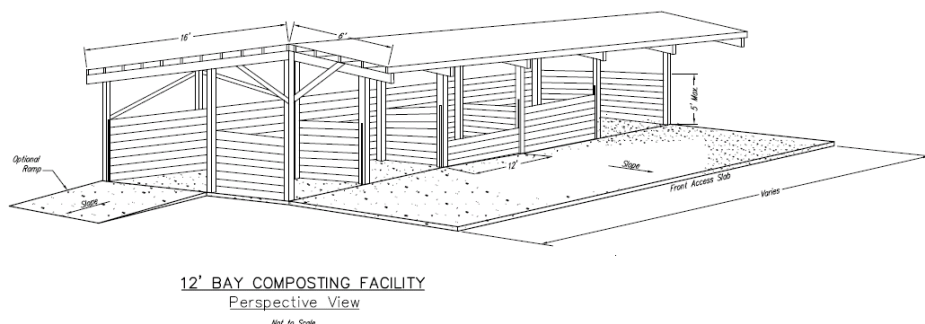12' BAY COMPOSTING FACILITY
Perspective View
Not to Scale

Figure 2: Diagram of a dead bird composting facility. Additional detailed drawings can be found at the USDA National Resources Conservation Service website, http://www.oh.nrcs.usda.gov/technical/engineering/cadd2_dwg_a_to_c.html (NRCS 1994).

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[2] A windrow is an elongated pile.

At least 3 bins are usually in operation at any one time—one being filled, another in the primary stages of composting and the other in the secondary stages of composting. A pile is sometimes substituted for the secondary bin in two bin systems (Keener *et al.* 2000). Bins are usually only used to compost small-/ and medium-sized carcasses. As a general guide, 10 m^3 of bin space is required for every 1,000 kg of carcass (Mukhtar *et al.* 2004).

Piles for mortality composting are usually constructed in the open on a hard stand. Placing a plastic or geotextile liner under windrows as a moisture barrier is recommended when a concrete pad is not available. Access to the pile from all sides should be possible and the pile is shaped to shed rainfall. Windrows are formed by continually extending the length of the pile with the addition of further mortalities and supplemental carbon. The length of the windrow is determined by loading rates and site layout. Mukhtar *et al.* (2004) described the recommended dimensions of windrows according to the relative sizes of carcasses:

- small carcasses (<23 kg): bottom width, 3.6 m; top width, 1.5 m; and height, 1.8 m

- medium carcasses (23–114 kg): bottom width, 3.9 m; top width, 0.3 m; and height, 1.8 m

- large and very large carcasses (>114 kg): bottom width, 4.5 m; top width, 0.3 m; and height, 2.1 m

In-vessel composting systems have also been used for composting carcasses. In-vessel systems enclose composting materials in a sealed chamber or vessel where environmental parameters such as temperature and aeration can be better controlled than in a pile or windrow. Examples include rotary composters, the BiobiN™ and the Ag-Bag® in-vessel system.

Rotary composters are suitable for small animals such as poultry (Fig. 3). For an 80,000 bird facility, about two 6 m^3 rotary bins are required (VFF 2001). The composter is simply filled with dead birds and the C source. The composter is rotated daily and composting is normally completed in about 2 to 3 weeks.

The BiobiN™ system is offered as a contracted service to the poultry industry in Australia. Bins of up to 9 m^3 in size are delivered to the poultry facility and, when full, are transported to a licensed composting facility to complete composting. The BiobiN™ is a fully enclosed system with forced aeration and a biofilter to control odours and leachate.

Figure 3: A typical rotary composter used in the Australian poultry industry (VFF 2001).

During an outbreak in British Columbia in 2004, 1 million AI-negative birds were disposed of using the Ag-Bag® in-vessel system (Spencer *et al.* 2005). The poultry carcasses and C source were mixed together and pushed into the Ag-Bag® (Fig. 4). The Ag-Bag® composting system was also used to dispose of 43,000 birds in the low-pathogenic AI outbreak in Virginia during 2002.

Figure 4: Ag-Bag® in-vessel composting system in use in Canada (DAFF 2005).

6.2. Equations for sizing composting systems

Keener *et al.* (2000) developed equations for animal decomposition times and sizing of composting systems based on a simple function of body weight. These equations were based on the findings of many researchers and are applicable for any species from 2 to 650 kg.

Primary cycle time (ie the time required to complete the primary stage of composting) in days, T_1, is given as

$$T_1 = 7.42 \times W_1^{0.5} \geq 10, \tag{1}$$

where W_1 is the largest body weight of mortality in kilograms.

The use of the minimum 10 days comes from the poultry composting work of Murphy and Carr (1991).

The required volume of the primary composter in cubic metres, V_1, is

$$V_1 = 0.0125 \times W_1 \times \text{Integer} (ADL \times T_1/W_1), \qquad (2)$$

where ADL is the average daily loss of mortality (kg/day) and Integer is the whole number obtained by rounding up the calculated value for ($ADL \times T_1/W_1$).

The secondary stage of composting is typically one-third of the primary cycle time. Therefore secondary cycle time in days, T_2 and volume in cubic metres, V_2 are given as

$$T_2 = 1/3 \times T_1 \geq 10 \qquad (3)$$

and,

$$V_2 \geq 0.0125 \times ADL \times T_2. \qquad (4)$$

Equation 4 should be modified for large carcasses and infrequent mortality cases so that

$$V_2 = 0.0125 \times W_1 \times \text{Integer} (ADL \times T_2/W_1). \qquad (4a)$$

Brodie and Carr (1997) recommended a minimum storage time of 30 days for finished compost. Thus storage time in days, T_3, is given as

$$T_3 \geq 30. \qquad (5)$$

The volume of storage for finished compost must be greater or equal to the volume of the secondary composter since it must hold all material emptied from the secondary composter. The storage volume requirement in m^3, V_3, is therefore

$$V_3 \geq V_2 \text{ or}$$

$$0.0125 \times ADL \times T_3. \qquad (6)$$

Equation 6 must also be modified for large carcasses and infrequent mortality cases so that

$$V_3 \geq V_2 \text{ or}$$

$$0.0125 \times W_1 \times \text{Integer} (ADL \times T_3/W_1). \qquad (6a)$$

Bins can be constructed to match the calculated primary, secondary and storage volume requirements within the general constraints that the maximum height should be 1.5–1.8 m and the minimum front dimension should be 60 cm greater than the loading bucket width (Keener *et al.* 2000; Mukhtar *et al.* 2004).

Where windrows are to be used, their length can be calculated by first estimating the cross-sectional surface area of the windrow. The surface area in m^2, A, of a typical mortality composting windrow is

$$A = H \times (B-H), \qquad (7)$$

where H is the height of the windrow and B is the width of the windrow base in metres (NRAES 1992). Equation 7 is a good estimate of surface area when the base width is greater than or equal to twice the height of the windrow. Equations for estimating the surface area of other shapes of windrows can be found in NRAES (1992).

The length of a primary composting windrow in metres, L_1, is then given as

$$L_1 = V_1/A. \tag{8}$$

When the length of the longest composting windrow is known, the required hard stand area can be calculated based on a 3-m spacing around and between windrows. The 3-m spacing allows for windrows to be mixed and turned.

6.3. Site selection and layout

The following general principles apply to site selection and layout for on-farm composting of mortalities (Mukhtar *et al.* 2004; Keener *et al.* 2006):

- the site should be in an elevated area of low permeability, at least 1–2 m above the watertable and not within 100 m of surface waters (e.g. streams, lakes, wells etc)

- the site should have an adequate slope (1–3%) to allow proper drainage of leachate and prevent pooling of water

- consideration should be given to prevailing winds and the proximity of neighbours to minimise problems associated with odour and dust

- run-off from the compost facility (e.g. from a 25-year, 24 hr rainfall event) should be collected and directed away from production facilities and treated through a vegetative filter strip or infiltration area

- the site should have all-weather access and have minimum interference from other traffic

- Maintaining an effective cover of C source over compost piles is usually sufficient to eliminate scavenging animals and vermin. But animals will dig into piles when they know mortalities are contained in them, so fencing should be installed around piles and bins to minimise this problem

7. The mortality composting process in detail

7.1. Carbon sources

A wide range of carbon sources can be used for mortality composting, including sawdust, wood shavings, green waste, chopped straw, manure, poultry litter and other bedding materials.

7.1.1. Performance of different carbon sources

The three most important properties that influence the performance of different carbon sources in mortality composting are available energy (biodegradability), porosity and moisture absorbency.

Sawdust is probably the most common C source used for mortality composting, as it is highly absorbent, allows high temperatures to be sustained and sheds rainwater when used for uncovered piles. According to Imbeah (1998), carbon sources like sawdust and rice hulls are ideal for mortality composting because their particle size allows them to settle intimately around the carcass to provide optimum contact.

Researchers rarely identify the type of C source beyond the generic term 'sawdust' despite the fact that the biodegradability of sawdust between timber species can differ

by a factor of more than 10. Data from Allison (1965) showed that hardwoods had significantly higher biodegradability than softwoods but there was considerable variation between various species, especially in the softwood family.

The absorbency of different types of bedding materials is also known to differ greatly (Burn and Mason 2005; Misselbrook and Powell 2005). In general, softwood sawdusts are more absorbent than hardwood sawdusts. The absorbency of a C source will influence the depth of the base layer that is needed to absorb liquids during composting, but also the performance of the outer layers as a biofilter.

Research by Ohio State University found that some C sources such as chopped straw or cornstover can be used in mortality composting piles, but they require periodic addition of water to maintain composting conditions (Keener and Elwell 2006). King *et al.* (2005) compared the performance of 11 different types of C sources for composting large carcasses (horses and cows). They reported that coarsely structured C sources such as wood shavings or wood chips experienced problems with odour, leachate and vector attraction. Glanville *et al.* (2005) studied straw/manure, corn stalks and corn silage as C sources for 450 kg cattle carcasses in windrows. From a biosecurity standpoint, corn silage performed best as it consistently produced the highest internal temperatures and sustained them for the longest time but it did not result in noticeably shorter carcass decay times.

In practice, a wide range of carbon sources can be successfully used in mortality composting. The choice of material is likely to be based on cost, availability and performance. It is commonly advised to incorporate up to 50% of finished compost into the base and cover C sources (Mukhtar *et al.* 2004; Kalbasi *et al.* 2005; Keener and Elwell 2006). The recycling of finished compost in this manner reduces the cost of purchase of raw materials, speeds up the initiation of composting conditions and reduces the space required for storage of finished compost. To facilitate faster rates of decomposition, some researchers recommend that carcasses should be added to C sources that are actively composting or those that have an ideal C:N ratio for composting (Kalbasi *et al.* 2005; King *et al.* 2005). The inclusion of too much finished compost in the initial mixture sometimes reduces decomposition rates because of a lack of available energy in the compost or reduced porosity in the final mix (Murphy *et al.* 2004; Keener and Elwell 2006).

7.1.2. Determining requirement for carbon

Recommendations differ on the amount of carbon required to compost mortalities. These include:

- a 12:1 sawdust to mortality volume ratio for all types of mortality (Keener *et al.* 2000)

- about 6m^3 of sawdust per 1,000 kg of pig mortality (DPIF 2005)

- about 9.5m^3 of C source for fully-grown cattle (Bonhotal *et al.* 2002)

- a carcass:straw:manure volume ratio for poultry of 1:0–1.2:4–8 (NRCS 2001)

The requirement for carbon can be estimated for composting all types of mortalities in either bins or static piles/windrows when the annual mass of mortality is known. The annual sawdust requirement in m^3/yr, V_s, is

$$V_s = YL \times 0.0116, \qquad\qquad\qquad (9)$$

where YL is the yearly mortality loss in kg/yr (Keener *et al.* 2000).

Equation 9 gives the total annual requirement, but up to 50% of this can be met by replacement of fresh sawdust with finished compost.

7.1.3. Available sources of carbon in Victoria

The most likely carbon sources for mortality composting in Victoria are sawdust, wood shavings, straw, poultry litter and green waste. Sawdust and wood shavings are readily available in Victoria at a cost of up to $13–18/m^3 depending on volumes and distance transported[3]. Stockpiles of poultry litter exist in the Melbourne area and this currently sells for about $8–10/m^3.

Green waste could be a potentially useful carbon source within 100 km of the major urban areas of Victoria (Melbourne, Geelong, Bendigo, Ballarat and Shepparton). The estimated amount of green waste produced in the whole of Victoria is about 678,000 t/yr (EcoRecycle Victoria 2003). About 40% of this is currently recycled at commercial composting facilities. Most of the recycled green waste in urban areas is tied up in supply contracts with local government. Nevertheless, agreements could be made in advance with commercial composters to supply the raw materials for composting in the case of an emergency. In this way, freshly hammermilled green waste could potentially be purchased for under $10/m^3 plus delivery[4].

In regional areas, much of the green waste collected by local government is stockpiled, hammermilled and is available for free (B. Grant, Sustainability Victoria, pers. comm. 2006). The Melbourne and Geelong areas also have stockpiles of course green waste (estimated to be 60,000–100,000 m^3) that could be hammermilled again and used for mortality composting. This is usually oversized material, screened out of compost prior to sale, but may be contaminated with plastics and other impurities. The cost[5] of hammermilling this material would be about $7–12/m^3.

Other potential sources of carbon could be ground-up timber from construction and demolition sources (519,000 t/yr). This includes cut-offs from timber product manufacturers, pallets and crates and residential demolition and construction (EcoRecycle Victoria 2003). About 28% of this material is currently recycled. On a more sporadic basis, timber from ex-plantation forestry becomes available for recycling. After the recent fires, some plantations were damaged and the low-grade timber in them is now being cleared and processed (B. Grant, Sustainability Victoria, pers. comm. 2006).

7.2. Pre-treatment of carcasses

The burial of mortalities above the ground in a pile of carbonaceous material does not necessarily result in optimum conditions for composting because of the heterogenous nature of the mix. But leaving the carcasses undisturbed until they are largely broken down has obvious advantages for biosecurity, particularly in an EAD outbreak. Nevertheless, Rynk (2003) demonstrated that chopping large carcasses in a vertical

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[3] In some parts of regional Victoria, sawdust and shavings can be obtained for free.
[4] Assumes that the cost of hammermilling is met fully by the minimum gate fee ($15/t) received for delivery of green waste into the facility. The $10/m^3 is therefore the profit margin for on-selling freshly processed green waste. As the gate fee for green waste is usually $20-30/t, the minimum sale price for freshly processed green waste could be lower than $10/t.
[5] Assumes a 100% volume reduction for re-grinding course green waste, daily hire of hammermill of $3,500 and a throughput of 250-300 m^3/day of product.

grinder-mixer (the type used for grinding hay and mixing feed rations) produces a homogenous mixture for composting and reverses the normal requirement of C source to mortalities from 4:1 to 1:4 by mass. Finely chopping large carcasses also results in a significant reduction in required composting time from about 180 days down to as low as 75 days. All of this has a significant effect on the economics of mortality composting. The advantages of chopping the carcasses of smaller animals, like poultry, are less clear because they typically break down much more quickly than large carcasses.

Combining chopping and/or mixing of carcasses with the use of in-vessel type composting systems (e.g. the Ag-Bag® system) could be feasible for disposing of non-diseased birds in an EAD outbreak.

Rynk (2003) described the advantages of this sort of approach to include:

- mortalities are isolated from the environment, reducing the risk of odours and scavengers plus the effects of the weather

- the containment reduces the amount of C source required because the carcasses do not need to be fully covered and the need to absorb liquids is not as critical

- the added degree of process control in in-vessel type composting systems (e.g. forced aeration) tends to accelerate the composting process compared to passively aerated systems

7.3. Bin composting

A base of sawdust or other suitable C source of at least 30 cm thickness should be placed on the floor of the bin to collect liquids that are released during composting. Larger animals may require a deeper base layer (up to 60 cm deep). Mukhtar *et al.* (2004) suggested that the ideal base layer is pre-heated litter, put in place about 2 days before carcasses are added. Carcasses can be layered within the bin with about 15–30 cm of absorbent bulking material (e.g. litter or sawdust) placed between each layer of mortalities. Mortalities must not be placed within 20–30 cm of the sides, front or rear of the bin. A final cover of damp sawdust or litter to a depth of 60 cm should be placed on the top of the pile (Fig. 5). This final cover acts as a biofilter for odour control and to insulate the heap. When the cover material is too dry or too wet, odours may be released and scavenging animals may be attracted to the pile (Keener and Elwell 2006).

When additional animals are to be added to a partially filled bin, half of the cover material is removed and a new layer of animals is placed on top. The new layer of mortalities is then covered with 60 cm of damp C source.

The pile is moved to a secondary bin when the last layer of mortalities is almost completely decomposed. To ensure that the pile reheats, it is watered and re-mixed. An additional 10 cm of co-composting cover material is added to ensure that any carcass pieces remaining are covered and odours are minimised.
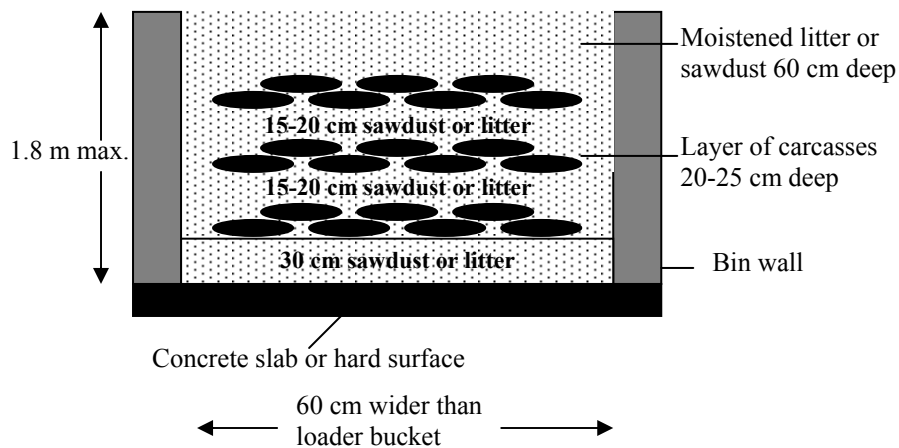
Figure 5: Typical layout of a mortality composting bin for small animals (adapted from Keener and Elwell 2006; Tablante and Malone 2005).

Stanford *et al.* (2000) used a bin (2.4 x 2.4 x 2.4 m) constructed of pressure treated timber to successfully compost lambs and mature sheep in both summer and winter conditions of Alberta, Canada. Alternate layers of composted sheep manure, barley straw and fresh sheep manure were used above and below a layer of mortalities. The expected heating pattern was not observed in one trial due to the excessive moisture content (31% dry matter) of the fresh sheep manure that was added to the bin. In this trial, 6 wethers (mean mass of 97.5 kg) were composted in a single layer over autumn and winter. Foul odours were observed when the contents of the bin were transferred to the secondary bin after 79 days. However, turning the compost into the secondary bin salvaged the pile and temperatures reached over 60°C even though the average ambient temperature was only -6.7°C (with a low of -35°C).

7.4. Windrow composting

Large and very large animals (e.g. mature cattle and pigs) are most suited to the windrow composting method. It is also the system that is most likely to be used in any mass mortality composting process. Keener *et al.* (2000) stated that for mature cattle or horses, it is preferable to construct a separate pile for each carcass.

Mukhtar *et al.* (2004) suggested that a base layer of C source should be 30 cm thick for small carcasses, 45 cm for medium carcasses and 60 cm for large carcasses. An ideal base layer for this purpose has been described as absorbent organic material containing sizeable pieces 10–15 cm long such as wood chips (Bonhotal *et al.* 2002; LEP 2003). Another layer (15–30 cm thick) of highly porous, pack-resistant bulking material can be added on top of the base layer to absorb moisture from the carcasses and to maintain adequate porosity. The dimensions of these base materials must be large enough to accommodate the mortalities with >60 cm space around the edges (Fig. 6).
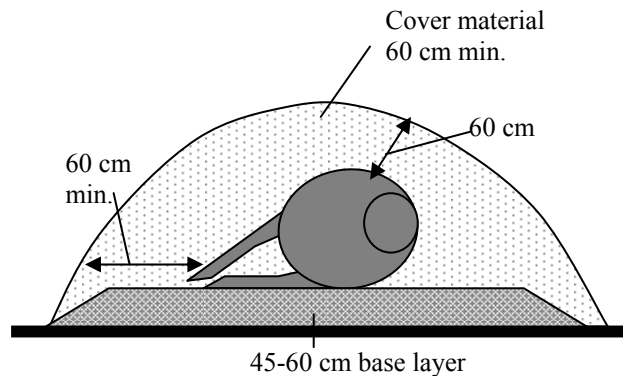
Figure 6: Cross-section of a typical windrow or static pile for larger carcasses.

An evenly-spaced layer of mortalities can then be placed on top of this and covered with between 30 cm and 60 cm of C source. Some guidelines recommend the use of a dry cover (e.g. Bonhotal *et al.* 2002), whereas others claim a moist C source reduces odours and assists in the breakdown of bones (Murphy *et al.* 2004; Keener and Elwell 2006).

Small-/ and medium-sized carcasses can be layered in windrows with at least 30 cm of C source placed between each layer until the windrow reaches a height of approximately 1.8 m. With larger carcasses, only a single layer of mortalities should be placed in a windrow.

For ruminants larger than 136 kg, it is usually recommended to lance the rumen and/or thoracic cavity to avoid bloating and possible explosion (Bonhotal *et al.* 2002; LEP 2003; MAFRI 2004). However, according to Murphy *et al.* (2004), experience has shown that this is not necessary. They claim that opening the body cavity may reduce the composting time by a couple of weeks, but the shorter time is not worth the possible knife danger and potential exposure to pathogens.

Straw bales were used by Murphy *et al.* (2004) to confine a U-shaped site of dimensions 2.6 m by 2.6 m and 1 m deep for composting beef cattle (275–450 kg). As base layers and covers, they used straw, manure compost and sawdust separately and in combination (ie 2 C sources in equal quantities). All six permutations of C sources produced an acceptable decomposition of the cattle mortality and no odours were observed. However, it was noted that straw and sawdust piles produced a more rapid rise in temperature and shorter times of decomposition.

Mukhtar *et al.* (2003) investigated a low-maintenance approach to composting cattle and horses in spent horse bedding (pine wood shavings and horse manure). The animals were composted in the bedding with or without wooden pallets under them (both on a 46 cm base layer). It was assumed that the air spaces between the pallets and the bedding layer underneath them would continue to aerate the static pile and that these piles would require less turning. The effect of the pallets was inconclusive as both methods worked successfully and the animals composted were of different sizes. Nevertheless, the trials showed that peak temperatures were often associated with the moist bottom layers of the pile as the upper layers dried out. Temperatures in the upper layers of the pile increased in response to rainfall.

In static piles of poultry mortalities, straw and hen manure, González and Sánchez (2005) found some influence of ambient temperatures and different mixes on the progress of composting. During summer, the carcasses were exposed to temperature above 60°C for between 4 and 20 days depending on the particular mix used. In winter, peak temperatures were lower, but still exceeded 55°C in each pile.

7.5. Monitoring composting conditions

The progress of composting is monitored primarily with a temperature probe. Temperature is the single most important indicator of the stage of degradation, the likely pathogen kill and the timing of turning events (Keener and Elwell 2006). Temperatures should be taken at several points near the carcasses in a pile—for example with the use of a stainless-steel temperature probe 90–100 cm in length.

A logbook should also be used to record data such as dates, mass of carcasses, temperature, amount and types of C sources used and dates when compost is turned (Mukhtar *et al.* 2004).

8. Managing environmental and public health impacts

Improper carcass disposal may cause serious environmental and public health hazards, including:

- generation of nuisance odours resulting from the anaerobic breakdown of carcasses

- leaching of nutrients from carcasses to ground and surface water

- spread of pathogens from infected carcasses via equipment, personnel, air, soil or water

- flies, vermin and scavengers disrupting operations and acting as potential vectors of harmful diseases

Many of these potential hazards are managed by paying careful attention to site design and layout. The biological risks associated with mortality composting are principally managed by proficient operation of the composting process and this is discussed in detail below.

The environmental impacts of cattle carcass composting were investigated by Glanville *et al.* (2005). Trials were conducted in 6 m x 5.5 m x 2.1 m windrow-type test units containing four 450 kg cattle carcasses on a 60 cm thick base layer of C source. C sources included corn silage, ground cornstalks or ground straw mixed with feedlot manure.

During the first 4–5 weeks after construction, air samples were collected on a weekly basis from the surface of the test units and compared with stockpiles of cover materials (i.e. not containing mortalities). Threshold odour levels were determined by olfactometry using experienced odour panellists and standard dilution procedures. It was found that 45–60 cm of cover material was generally very effective at retaining odorous gasses produced during composting. Threshold odour values for the composting test units were often very similar to the odour intensities found in the cover material stockpiles.

Chemical analysis of the leachate collected in PVC sampling tubes installed at the base of the test units showed that it had high pollution potential (Glanville *et al.* 2005). The leachate had mean ammonia concentrations of 2,000–4,000 mg/L, total organic C of 7,000–20,000 mg/L and total solids of 12,000–50,000 mg/L. Nevertheless, the base and cover materials were highly effective in retaining and evaporating liquids released during composting as well as that contributed by seasonal precipitation. Following a 5-month monitoring period after the set up of the trial, the test units received nearly 546 mm of precipitation yet released less than 9 mm of leachate each.

In Nova Scotia, Rogers *et al.* (2005) investigated the environmental impacts of composting pigs in sawdust and pig litter (manure plus bedding). Leachate and surface run-off were collected and analysed for various water quality parameters. Highest temperatures and better carcass decomposition were observed with sawdust in both the primary and secondary stages of composting. The sawdust cover also had lower leachate and surface run-off volumes and annual nutrient loadings compared to the pig litter treatments.

Finished mortality compost should be applied to land in a manner similar to manure so that the nutrient uptake capabilities of the crop being grown is not exceeded (DPIF, 2005). A comparison of the nutrient composition of poultry litter and mortality composts is shown in Table 2.

Table 2: Nutrient composition of lamb and sheep mortality compost, poultry litter and poultry mortality compost.

	Lamb mortality compost[1]		Sheep mortality compost[1]		Poultry litter[2]	Poultry mortality compost[3]	Poultry mortality compost[4]
	Starting compost	Finished compost	Starting compost	Finished compost	Uncomposted	Finished compost	Finished compost
	Mean (SD)		Mean (SD)		Mean (SE)	Mean (SD)	Mean (SD)
DM (%)	52.7 (8.1)	65.3 (5.5)	64.6 (1.4)	50.6 (5.4)	80.5 (0.58)	85.41 (11.31)	63.8 (10.62)
Total C (%)	23.5 (0.8)	23.1 (2.0)	23.5 (1.4)	28.3 (2.9)		27.40 (15.75)	36.3 (3.83)
Total N (%)	1.6 (0.1)	1.8 (0.2)	2.00 (0.2)	2.3 (0.2)	4.00 (0.72)	2.42 (0.93)	3.80 (0.55)
C:N ratio	14.3 (0.8)	12.7 (2.1)	11.9 (0.4)	12.2 (2.0)		10.96 (2.01)	9.8 (0.16)
Total P (%)	0.6 (0.0)	0.8 (0.1)	0.8 (0.1)	0.9 (0.1)	1.56 (0.047)	3.1 (0.91)	1.8 (0.55)
Total K (%)	2.42 (5.0)	12.16 (2.28)	14.31 (2.62)	13.55 (1.35)	2.32 (0.059)	2.88 (1.82)	2.1 (0.55)

[1]Stanford *et al.* (2000). Compost composed of mortalities, straw, manure and composted manure. Number of samples not given.
[2]Stephenson *et al.* (1990). Analysis of 106 broiler litter samples collected in Alabama, USA.
[3]González and Sánchez (2005). Analysis of 8 samples of compost with different ratios of straw, hen manure and poultry mortalities.
[4]Cummins *et al.* (1993). Analysis of 30 poultry mortality composts collected from farms in Alabama, USA.

Poultry mortality compost often has a higher nutrient content than other composts, probably as a result of the high nutrient content of poultry litter (Table 2). During composting, much of the available nitrogen is converted to organic forms and

becomes unavailable in the short-term to plants. Murphy and Carr (1991), for example, demonstrated much slower rates of N mineralisation in a loamy sand amended with poultry mortality composts compared to manure. Thus there is a lower risk of nutrient leaching with compost compared to uncomposted manures and mortalities. Nevertheless, it is advisable not to spread mortality compost in sensitive areas such as watercourses, gullies and public roads (DPIF 2005).

9. Cost of mortality composting

The cost of mortality composting will vary greatly from one operation to the next. In addition, comparisons need to be made with alternative disposal options, and the most economical option is also likely to vary according to individual circumstances.

Mescher (2006) listed the following factors to consider when comparing the economics of alternative disposal methods:

- volume and weight of mortality produced per established time period

- frequency of mortality occurrence

- required facilities and equipment (new and existing) and their useful life expectancy

- labour requirements

- accessibility and timeliness

- impact on the environment

The highest set-up costs are generally for large-scale composting bins with a concrete floor and steel roof. The set-up costs for pile/windrow systems are 1/3 to 2/3 less than large composting bins (Mescher 2006). When established, both bin composting and pile/windrow systems require little further investment and have similar labour requirements compared to other disposal options.

Crews *et al.* (1995) evaluated the annual net cost of different poultry carcass systems including a disposal pit, incineration, fermentation, refrigeration, large-bin composting and small-bin composting. The large-bin composting system was described as a two-stage process with the construction comprising of a weight-bearing concrete foundation, walls made of pressure treated timber, and a roof. The small-bin composting system was a single stage process of simpler design and a construction cost of about 25% of the large-bin system. It was assumed that the small-bin composting system would be operated without a tractor-loader.

For a flock size of 100,000 birds, the net cost of the small-bin composting system was similar to the disposal pit (US$0.077–0.081 per kg carcass disposed), whilst incineration and refrigeration were the most costly (US$0.196–0.251 per kg). In comparison, large-bin composting and fermentation were moderately costly (US$0.1–0.11 per kg).

The net cost of each disposal system was affected to a different degree by flock size. The greatest reduction in net costs (53–60%) was found with the fermentation and large-bin composting systems when going from a flock size of 40,000 to 200,000. The least responsive to increasing flock size was refrigeration (10.6% reduction), whilst the disposal pit, small-bin composting and incineration were moderately responsive with a 26–29% net cost reduction. At a flock size of 200,000, the net cost

of the fermentation and large-bin composting systems were competitive with the disposal pit (Crews *et al.* 1995).

A similar economic analysis was conducted by Henry *et al.* (2001) to evaluate 5 different carcass disposal options for a 300 sow farrow-to-finish system with an estimated mortality of about 88 t/yr. Two types of composting systems were compared with incineration (+/- an afterburner to reduce emissions) and rendering at 4 pickups per week. The first composting system, the 'high investment' version, was a 7-bin facility with a concrete apron, concrete floors, walls and roof (estimated construction cost of US$15,200). The second, a 'low investment', 6-bin facility was similar in design except it did not have the concrete apron or roof (estimated construction cost of US$7,850).

The highest cost option (US$0.36/kg mortality) was rendering at 4 pickups per week assuming that the service was available at US$25 per pick-up. This cost could be reduced to US$0.145/kg if only 1 pick-up per week was required. Incineration was the cheapest of the options, but this was at a diesel fuel price of US$0.29/L ($1.10/US gal) in 2001. At current US prices for diesel (US$0.68/L), the total annual cost for incineration would increase by about 40%. At this fuel price, the cost of operating the incinerator with the afterburner would be similar to the 'low-investment' composting option at about US$0.2/kg mortality. Current Australian prices for diesel (about AU$0.97/L with diesel fuel rebate), may make incineration cost prohibitive. The 'high investment' composting option cost about US$0.25/kg mortality to operate.

Both the analyses of Crews *et al.* (1995) and Henry *et al.* (2001) compared bin composting in a constructed facility with alternative disposal options. However, composting can also be performed in simple bin-type structures (e.g. using round bales to confine the pile) or in windrows and piles. Bonhotal (2005) estimated the cost of composting a fully-grown cow in New York State to be $US37.60. Bonhotal's cost estimate is based on the reuse of finished compost to construct new piles and a 30% loss in volume during composting. Thus each new pile is constructed with 30% fresh sawdust and 70% finished compost. Keener and Elwell (2006) recommends that no more than 50% of the volume of a pile should be made up of finished compost in case carbon availability becomes limiting.

Using similar assumptions to Bonhotal, and adjusting for Australian material and labour prices, this cost would be between $AU72.14 and $100.64 per cow depending on the requirement for fresh sawdust (Table 3).

Table 3: Estimated costs of composting a fully-grown cow in a static pile in Australia.

Item	Requirement	Rate	Total
Replacement sawdust[1]	2.85–4.75 m^3	$15 / m^3	$42.75–71.25
Tractor operation (90 HP)[2]	0.5 hr	$28.79 / hr	$14.39
Labour	0.5 hr	$30 / hr	$15.00
Total per cow			$72.14–100.64

[1]Based on reuse of finished compost. The lower cost in the range is for replacement of the portion of compost that is lost during composting (30% of 9.5 m^3 per cow). The higher cost in the range assumes that 50% of the pile volume is replaced by fresh sawdust. Price for hardwood sawdust from Brown's Sawdust and Shavings Supplies, Melbourne.

[2]Hourly operation includes depreciation, interest, insurance and running costs (DPI NSW, 2006).

10. Biosecurity aspects

10.1. Pathogen inactivation

10.1.1. General theory

Composting is a well-established pathogen reduction technology. It is known to control nearly all pathogenic viruses, bacteria, fungi, protozoa (including cysts) and helminth ova to acceptably low levels. Exceptions to this are the endospore-forming bacteria (e.g. *Bacillus anthracis*) and prions like BSE (bovine spongiform encepalopathy) (Kalbasi *et al.* 2005). Prions are highly resistant to both physical and chemical means of inactivating pathogens and for this reason it is assumed that composting will be ineffective in reducing infectivity of prion-infected carcasses.

Multiple mechanisms are known to be involved in the inactivation of pathogens during composting, such as temperature production, microbial antagonism (including antibiotic production and direct parasitism), production of organic acids and ammonia and competition for nutrients (Epstein 1997). Not only is temperature considered to be the most important factor in pathogen inactivation, it is also relatively easy to measure during composting.

The heat required for the inactivation of pathogens is a function of both temperature and length of exposure and this has been calculated to be between 200 and 400 BTU/g-mol for most spores and vegetative cells (Haug 1993). Consequently, exposure to an average temperature during composting of 55 to 60 for a couple of days is usually sufficient to kill the vast majority of enteric pathogens.

It is common to observe straight lines (or nearly so) through time-temperature survival data in semilog plots. Thus the inactivation of pathogens can be modelled using the first order equation (Haug 1993)

$$dn/dt = -k_d n, \tag{10}$$

where n is the viable cell population and k_d is the thermal inactivation coefficient (or decay rate).

10.1.2. Sensitivity of some animal diseases to heat and composting conditions

The AI virus is known to be relatively heat sensitive but it is able to survive for long periods in the environment under some conditions. According to AUSVETPLAN (AHA 2005), highly pathogenic AI virus (HPAIV) is killed when exposed to 70°C for 30 minutes, 75°C for 5 minutes and 80°C for 1 minute. HPAIV has been isolated from contaminated water for up to 4 days at 22°C and more than 30 days at 0°C (Webster *et al.* 1978). Stallknecht *et al.* (1990) estimated infectivity to be maintained in lake-water for more than 207 days at 17°C and 102 days at 28°C.

Senne (1994) investigated the effects of poultry carcass composting on the survival of HPAIV and the adenovirus that causes egg drop syndrome-76 (EDS-76). Tissues collected in dialysis bags from eight-week old chickens inoculated with one of these viruses were composted in alternating layers of straw, goat manure and chicken carcasses. After the first 10 days of composting, HPAIV had been totally inactivated

and only 1 out of 20 tissue samples yielded the adenovirus of EDS-76. A further 10 days of composting completely eliminated both viruses.

Glanville *et al.* (2005) investigated the survival of vaccine strains of poultry viruses placed inside compost piles constructed with cattle carcasses and different C sources. Newcastle Disease Virus (NDV) was selected as an indicator virus because it is a single-stranded RNA enveloped virus that is highly representative of other viruses, such as influenza viruses, that commonly threaten animal populations. Survival times of viruses were much shorter when viruses were exposed to the full range of environmental conditions (not just heat) present within the composting pile. NDV exposed to full composting conditions in dialysis cassettes, survived fewer than 21 days during cool weather, and fewer than 7 days during warm weather. Avian encephalomyelitis was inactivated within 7 days. Glanville *et al.* also evaluated the biosecurity of uncovered composting windrows containing eggs inoculated with NDV and avian encephalomyelitis. Specific pathogen-free (SPF) sentinel chickens were stationed in cages about 3 m from the windrows. Of 72 SPF sentinel birds stationed around the windrows only 1 bird showed a positive immune system response for avian encephalomyelitis antibodies indicating a possible release from the carcass composting trials.

No known published studies have directly investigated the effects of composting on the survival of the Foot and Mouth Disease virus (FMDV). However, Turner *et al.* (2000) studied the effects of heat treatment on the survival of FMDV, Aujeszky's disease virus (ADV) and classical swine fever virus (CSFV) in pig slurry. The viruses were inoculated in pig slurry that had been heated to the required temperature in a water bath. Both ADV and FMDV survived for more than 10 min at 55°C, but were eliminated at 62°C during the same time period. CSFV was less thermally stable than either ADV or FMDV and was eliminated to below detectable levels after 3 min at 60°C.

FMDV is known to be sensitive to the pH changes that accompany *rigor mortis*. The virus may survive for long periods in blood clots, bone marrow, lymph nodes, and the kidneys and liver because these tissues are protected from the pH changes that accompany *rigor mortis* (Bachrach 1968). Turner and Burton (1997) discussed the interaction of temperature and pH on the survival of viruses in pig slurry. It is thought that some of the virucidal properties of pig slurry are related to production of ammonia as this increases with temperature and at a pH over 8.

The microbiological safety of composted poultry farm mortalities were investigated by Conner *et al.* (1991). The primary composting stage was conducted in bins measuring 1.52 m wide and 1.52 m deep. Daily poultry mortalities from a broiler farm in Alabama were placed between layers of litter (manure and shavings) and wheat straw to a final depth of 1.5 m and held for 8–10 days post-filling. The compost was then transferred to a secondary bin 1.52 m wide and 2.44 m deep for an additional 17–21 days. Enteric bacteria (*Salmonella typhimurium, S. enteritidis, S. senftenberg, Pasteurella multocida, Listeria monocytogenes* and *E. coli* 0157:H7) were either inoculated directly onto carcasses or into tubes of brain heart infusion with 0.5% agar. In 2 out of 3 tests with carcasses inoculated with *S. typhimurium,* the pathogen was eliminated within 6 days of primary composting. In the 3rd test, *S. typhimurium* was not eliminated until the early stages of secondary composting (following 9–10 days in the primary bin and an additional 5–10 days in the secondary bin). Test tubes containing the other pathogens were placed into both hot and cooler

zones of the bins. Attempts to recover the pathogens failed at the end of 14 days primary composting and again after an additional 14 days of secondary composting.

10.2. *Microbiological risk assessment and management*

10.2.1. General comments

Despite the extensive literature available in the general field of composting, there have been very few published reports in peer-reviewed journals specific to mortality composting. Still fewer papers describe studies on the survival of pathogenic organisms in mortality composting. Nevertheless, a wealth of information is available on the sensitivity of pathogens to environmental conditions and, to some extent, composting conditions.

Analytical techniques are well developed to quantitatively predict the survival of pathogens through simulation modelling, but have not been applied directly to mortality composting.

Gale (2002) used simulation modelling to assess the risk of using composting to treat catering waste containing meat. The risk to animal and human health from the application of composted catering waste was quantified using the 'source – pathway – receptor' approach. The risk assessment focussed on transmissible spongiform encephalopathy (TSE) agents, exotic pig viruses, *E. coli* 0157, *Campylobacter*, *Salmonella*, NDV and parasites. From the study, the following specific recommendations were developed for managing the composting process and the application of composted catering waste to land:

- all steps should be taken to eliminate raw material bypassing thermophilic composting

- a two-stage composting process should be used for catering waste containing meat. The first stage of composting of at least 14 days should be in an in-vessel system or enclosed windrow. The second stage of composting (at least 14 days) could be conducted in windrows, but these must be turned at least 3 times

- during both stages of composting, the catering waste must be exposed to at least 60°C for 2 days

- the maximum particle size for composting must be <40 cm (equivalent to large joints of meat)

- equipment for handling the raw material must be kept separate from that handling the end product

- a withholding period of 2 months is required for animals grazing pasture to which composted catering waste has been applied

This type of risk assessment could be usefully applied to the development of standard operating procedures for animal mortality composting. Stochastic modelling would be particularly useful as it attempts to account for uncertainty in the input data. Some of the important issues for conducting such a risk assessment are discussed below.

10.2.2. Risk of infected material bypassing thermophilic composting

To achieve efficient pathogen reduction, all materials in a compost pile must be exposed to high temperatures for prolonged periods. In a fully enclosed composting system such as an in-vessel reactor, high temperatures can be achieved within a few centimetres of the edge of the composting mass. In piles or windrows, there is greater variation in the temperature profile from the cool outside layers to the hot central mass. As a result, piles and windrows are usually turned periodically to expose the outer layers of the pile to high temperature composting.

In conducting the risk assessment on catering waste, Gale (2002) pointed out that it is not so much whether a 2- or even 7-log reduction of pathogens occurs at any given time-temperature treatment, but how much material actually bypasses the hot composting process.

Assume that a compost pile has an outer cooler zone where temperatures are sublethal and no pathogen destruction occurs and an inner hotter zone where complete thermal inactivation occurs. When the pile is turned at time intervals of Δt and a random redistribution of material occurs, the number of pathogens surviving (n_t) can be described as

$$n_t = n_0 \left[f_l + f_h \, e^{(-k_d \Delta t)} \right]^N, \tag{11}$$

given that

$$f_l + f_h = 1, \tag{12}$$

where n_0 is the number of pathogens initially present, f_l is the fraction of compost in the sublethal temperature zone, f_h is the fraction of compost in the lethal temperature zone and N is the number of pile turnings (Haug 1993).

Assuming that a given proportion (π) of pathogens survive the high temperature zone, n_t can be given as

$$n_t = n_0 \left[f_l + f_h \pi \right]^N. \tag{13}$$

About 3 or more turns of a windrow would be required to achieve a 99.9% reduction in pathogen numbers, if there were 1,000 (3-log) pathogen counts in a windrow initially ($n_0 = 3$), >80% of compost was in the hot zone ($f_h = 0.8$), and the proportion of pathogens surviving in the hot zone was 0.01 or less.

Despite its importance to pathogen reduction, few studies have shown the cross-sectional temperature profile of windrows and accurately determined the proportion of material exposed to lethal temperature conditions (ie f_h in equations 11–13). Temperature profiling by Joshua *et al.* (1998) showed that >60% of the cross-sectional area of windrows was exposed to temperatures above 55°C in 7 out of 15 days. The windrows, measuring 2.5 m high by 3.5 to 4.5 m wide, were turned only once during this period and were comprised of green waste. Similarly, Wilkinson *et al.* (2003) studied the effect of turning on the windrow temperature profiles of poultry litter. Trials were conducted with unamended litter (ie the litter was not adjusted for moisture content or C:N ratio) formed in windrows of dimensions 1.6 m high and 3 m wide. Key differences were observed in the middle period of the trial (3–9 weeks) where only 7% of the cross-sectional area of the static windrow were exposed to temperatures above 45°C. In the turned windrow during the same period, about 54% of the litter were exposed to the same temperature conditions.

Analysis of static (unturned) composting piles can be conducted provided that temperature distributions in the pile are known. Whilst virtually all mortality composting studies provide temperature monitoring data, these data are seldom comprehensive enough to estimate percentage bypass.

Burge *et al.* (1978) examined 15 aerated static piles composting a mixture of raw biosolids and wood chips. Temperatures were monitored throughout the composting process from the centre of the pile, lateral portions extending out from the centre, as well as just below the outer blanket at the lower edge of the pile. This latter area is usually exposed to the lowest temperature during composting. Despite the lower temperatures observed in the lower edges of the 15 piles surveyed, there was a high level of confidence that any particular time/temperature regime would be achieved. For example, there was a 99.9% chance that temperatures above 55°C would be achieved for 9.4 days (Table 4).

Confidence levels will vary between operations so proficient design and operation are needed to establish confidence that all material achieves an adequate time/temperature profile. This is supported by the work of Christensen *et al.* (2002) which found considerable variation in temperature profiles between different windrow and in-vessel composting systems.

Table 4: Number of days during which biosolids compost achieved a minimum temperature at individual confidence levels (Burge *et al.* 1978).

Temperature (°C)	Confidence Levels (%)		
	95	99	99.9
≥50	13.8	13.3	12.6
≥55	10.6	10.1	9.4
≥60	7.3	6.8	6.3
≥65	4.3	3.9	3.4
≥70	1.2	1.0	0.8

10.2.3. Effect of particle size on efficiency of heat inactivation

Large clumps of solids reduce the efficiency of heat inactivation in a composting pile because they take longer to heat than smaller particles.

Taking the worst-case scenario of a particle of high density and specific heat and low thermal conductivity, Haug (1993) showed that the time taken in hours, t, for the centre of a particle to reach a temperature close to the surrounding temperature can be given as

$$t = 0.1R^2, \qquad (14)$$

where R is the radius of the particle in cm, given that

$$(T - T_0)/(T_1 - T_0) = 0.9, \qquad (15)$$

where T_0 is the temperature of the particle when it goes into the compost, T_1 is the temperature of the surrounding compost material and T is the desired temperature for pathogen destruction.

Thus a particle of 20 cm radius in a compost heap will take 40 hr to reach an internal temperature that is close to the surrounding compost temperature.

Gale (2002) used these equations to determine the minimum time/temperature treatment for composting catering waste assuming that an FMDV-infected leg of pork with a bone in of 20 cm radius (R) could be part of the material composted and the desired temperature for pathogen destruction was 56°C (T). Assuming the initial temperature of the leg (T_0) was 20°C, exposure to 60°C (T_1) for 2 days was deemed to be sufficient for pathogen destruction.

10.2.4. Pathogen re-growth

Under certain conditions, enteric bacterial pathogens are known to be able to regrow in composted organic materials when temperatures decline to sublethal levels. This is not the case for obligate parasites or organisms that require hosts to multiply such as viruses, protozoa and helminth pathogens.

Moisture, carbon availability and microbiological competition are the key factors that influence the regrowth of pathogens in composts (Russ and Yanko 1981; Hussong *et al.* 1985; Soares *et al.* 1995).

Hussong *et al.* (1985) concluded that the active indigenous flora of compost establishes a homeostatic barrier to colonization by *Salmonella* sp., and in the absence of competing flora, reinoculated salmonellae may grow to potentially hazardous densities. They found that when inoculated in irradiation sterilised composts, salmonellae grew at a rate of 0.65 doublings per hr for over 24 hrs. For Russ and Yanko (1981), the C:N ratio served as a long-term nutritional indicator of salmonellae regrowth potential in biosolids composts. Thus, when the C:N ratio was under 15:1, available carbon was limiting and repopulation did not occur.

The stability of compost is of critical importance to prevent the regrowth of pathogens. Stability is a measure of the potential microbial activity in compost and this is a function of substrate availability (Bernal *et al.* 1998). A stable compost also supports a diverse microbiological flora that out-competes pathogenic organisms. Stabilisation occurs after the peak-heating phase and continues into the curing or maturation phase of composting.

Sometimes compost appears to be stable but it is only so because it is too dry to support high rates of microbiological activity. Upon re-wetting of these composts, an ideal environment can be provided for pathogens to repopulate. Soares *et al.* (1995) found this to be the case for two biosolids compost samples collected from commercial compost facilities. These samples were initially very dry (80.4–81.6% dry matter) but supported the repopulation of *E. coli* when the samples were adjusted to 50% dry matter content by adding water and incubated.

Due to its low C:N ratio and available carbon, poultry litter heats up readily even when it is relatively dry (>80% dry matter). Although high temperatures give the impression that composting is occurring at a rapid rate in dry poultry litter, low moisture content limits the progress of stabilisation. Even though high internal temperatures were consistently achieved in dry poultry litter (77–84% dry matter),

Wilkinson *et al.* (2003) showed that the populations of *E. coli* in the outer layers did not diminish even after the windrows were turned. In this case the outer layers of the windrows were found to be an ideal environment for the persistence and regrowth of enteric bacteria, especially after the moistening effects of rainfall.

10.2.5. Risk management

The discussion above highlights the importance of proficient design and operation of mortality composting systems to ensure that all material achieves an adequate time/temperature profile for the destruction of pathogens. Confidence that this is achieved for mortality composting piles is possible even though they are not usually turned until after completion of the primary stage of composting, provided that the temperature profiles are known. Additional confidence can be given by the fact that the length of the composting process for mortalities (with the exception perhaps of small animals) is usually much longer than in conventional composting systems.

The current state of knowledge suggests that taking the following factors into consideration will reduce the microbiological risks associated with mortality composting:

- attention to site design and layout to minimise scavenging and contamination of ground and surface water with pathogens

- using a minimum two-stage composting system followed by the use of a curing phase to achieve a stable end product

- where possible, confine pathogens to the central hot zone of the compost pile by fully encapsulating mortalities in 'clean' C source

- use sufficient C source to absorb liquids and odorous gasses produced during composting

- monitor and manage the composting process to maximise progress towards stabilisation (e.g. temperature, monitoring, watering and turning)

- attention to basic standards of hygiene (e.g. minimising pooling of water at the site, regular sanitising of equipment and keeping it separate from production facilities, use of personal safety equipment by compost operators)

11. Mass mortality composting

11.1. History

Mortality composting has mainly been used for managing routine mortalities, although researchers at the Universities of Maryland and Delaware first proposed using it to dispose of mass poultry mortalities. There are numerous instructions for constructing composting systems for dealing with mass poultry mortalities now available on the Internet (e.g. Murphy and Carr 1991; Carr *et al.* 1998; Tablante and Malone 2005; Tablante *et al.* 2002; Ritz 2005).

Until recently, most mass mortality composting operations were conducted after catastrophic events such as flock losses due to heat stress or herbicide contamination (Malone *et al.* 2004). There are relatively few examples of the use of composting to

manage disposal of carcasses in an EAD outbreak. Nevertheless, the limited experience to date with composting in EAD situations shows some promise.

11.2. Description of process for poultry mortalities

This information was adapted from the mass poultry mortality composting guidelines of Tablante and Malone (2005), considering earlier work (e.g. Murphy and Carr 1991; Carr *et al.* 1998) and the experience gained in the Virginia (2002) and Delmarva (2004) AI outbreaks. Depopulation procedures (euthanasia) are not discussed, as they are unlikely to change with the choice of disposal method.

11.2.1. Outline of procedure

The following steps outline the overall process:

1. consult appropriate authorities to gain approval and/or assistance on depopulation and sanitation procedures and to conduct an initial assessment of the best methods of carcass disposal based on farm circumstances

2. conduct a thorough farm evaluation to determine if composting is an option and whether additional sawdust (or other suitable C source) will be needed

3. develop a plan of action for composting to minimise material handling and amount of sawdust needed. Consider shed layout (e.g. access for equipment, ceiling height, ability to turn piles), bird age, location and number of the dead, amount and condition of litter in the shed

4. develop or obtain a pre-approved list of personnel, equipment and supply needs

5. implement and monitor composting process to completion

6. with the approval of the appropriate authorities, dispose of the finished compost or apply it to land

11.2.2. Determining litter requirements

Additional litter, sawdust or other C source may need to be delivered because the litter in the shed may not be sufficient to complete the composting process. As a general rule, 4.2 mm of litter is required per kg of carcass per m^2 of floor space (0.8 inches/lb/ft^2). Thus, the required total depth of litter in mm, D_t, is given as

$$D_t = 4.2 \times (W_t/A_s), \qquad (15)$$

where W_t is the total weight of mortalities in the shed (kg) and A_s is the surface area of the shed in m^2.

It follows then that the amount of additional litter, sawdust or other C source that is required in m^3, V_r, is

$$V_r = (D_t-D_e)/1{,}000 \times A_s, \qquad (16)$$

where D_e is the average depth of litter in the shed in mm.

If turkeys are to be composted, or if the layering method is used for broilers, the minimum required depth of litter increases to approximately 5.2 mm/kg/m^2.

11.2.3.   Personnel, equipment and supplies

Tablante and Malone (2005) suggest that a person experienced in composting should oversee the operation. This person should also be trained in the particulars of mass mortality composting. In addition, an experienced bobcat operator is required as well as additional labourers to assist each bobcat and for cleaning and sanitising equipment.

One medium-size loader (bucket capacity of about $1m^3$) is needed to form the windrows, and an additional smaller loader is useful for cleaning up litter and carcasses around the shed. Two labourers are required to assist each loader. With this level of resources, windrow set-up in up to 2 sheds should be complete in 8–12 hr.

Where there are multiple sheds on a farm undergoing this procedure, the number of loaders and personnel will need to be increased (e.g. for 4 houses, 3 loaders and 6 personnel would be required).

A typical list of supplies and equipment required for in-shed composting of broilers includes:

- personal protective equipment (e.g. coverall suits, boots, gloves, respirators)[6]

- hand tools (e.g. square point long handle shovels, pitchforks, long handle rakes and hoes, stick broom, drill with feeder winch attachment, ladder, hammer, crowbar and cutting pliers)

- personal supplies (e.g. toilet facilities, mobile phone, food, drinks, paper towels and disinfectant hand wipes)

- rodenticide and insecticide

- composting thermometers

- carbon source (if needed - litter, sawdust, etc)

- water hose or water supply (if needed)

- warning signs

- tarpaulin, plastic sheet or fleece with anchors (if needed)

- cleaning and disinfectant supplies (e.g. large garbage bags, bucket, brush, hand sprayer)

- poly removal supplies (if needed - tow rope, fuel source, lighter, disposal approval)

11.2.4.   Suitable composting methods

In preparing the shed for composting, plastic sheets, tarpaulins or other materials used in the depopulation procedure should be removed from the shed and deposited elsewhere on the farm for ultimate disposal. Feeder and drinker lines are raised and a rotary tiller is used if the floor of the shed is caked in dried litter.

Tablante and Malone (2005) described three main methods of composting:

- the layering method

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[6] Special care is needed for zoonotic diseases for which a higher level of personal protection may be required.

- shredding and piling

- mixing and piling

The recommended composting method depends on the depopulation procedure. If the depopulation procedure results in a concentration of poultry in a small section of the shed, then the layering method might be most appropriate. But when the carcasses are spread more evenly across the shed, the mixing and piling method is recommended.

The layering method is essentially the same as described above for the routine management of mortalities. A bobcat is used to layer carcasses in a windrow with dimensions of 3–4 m at the base and up to 1.8 m high. Each layer of mortality should be no deeper than 25 cm with 15–20 cm of litter/sawdust between each layer. The final windrow should be capped with 15–20 cm of litter/sawdust and to ensure that all carcasses are covered. Each layer of birds should be watered to thoroughly wet the feathers (1 L/kg carcass), but care should be taken not to saturate the sawdust (Tablante *et al.* 2002).

The piling method involves the least time, labour and materials. Unless supplemental sawdust is required, the birds are first removed from along the side-walls to gain access to the litter there for capping windrows. Carcasses are spread evenly across the centre of the shed and rolled up together with litter to form windrows 3–4 m at the base. The litter from along the side-walls (or supplemental sawdust) is then used to cap the windrows (15–20 cm thick).

The shredding and piling method follows the same process as the piling method except that carcasses are shredded or crushed prior to forming the windrows. This is most suitable for larger birds such as turkeys, or where there is a desire to speed-up decomposition. Carcasses can be shredded by the use of a rotary tiller attached to the back end of a bobcat or tractor (Fig. 7). Alternatively, carcasses can be crushed with a loader prior to constructing the windrows (Fig. 7).

Figure 7: Shredding (left) and crushing (right) poultry prior to construction of windrows (Tablante and Malone 2005).

Bendfeldt *et al.* (2005) investigated the use of in-shed composting of turkey mortalities as a rapid response to catastrophic losses. The use of composting in the turkey industry had not been considered a viable option previously because of the

perception that it would not work on larger birds. Four different C sources (hardwood sawdust, woodchips, built-up litter and starter litter) proved to be effective in composting the turkey mortalities, and after 2 weeks of composting, few carcasses remained in any of the windrow treatments. Bendfeldt *et al.* (2005) demonstrated that temperatures above 60°C were achieved within 5 days in windrows constructed with crushed or shredded turkeys and 16 days for whole carcasses. In addition, they reported that to compost crushed or shredded carcasses, 30% less carbon material was required compared to whole carcasses. Windrows formed from crushed or shredded carcasses also do not require additional water to be added.

Any surplus litter not used in the composting process should be formed into windrows and composted to inactivate pathogens. Following construction of the windrows, all tools and equipment must be removed from the shed and properly sanitised.

Windrows need to be monitored in multiple locations to ensure that temperatures in excess of 55°C are reached within 5 days of construction. After 10–14 days, the temperature may start to decline. The windrows should then be turned either inside the shed, or by reforming them outside of the shed. If windrows are moved outside, they should be covered, for example with tarpaulin. Following turning, windrows should be capped again with sawdust or litter to a minimum depth of 100 mm.

After an additional 2–3 weeks, the compost can be applied to land with the approval of the relevant authorities.

11.3.   Experience gained in EAD outbreaks in the USA

11.3.1.   Virginia, West Virginia and North Carolina, 2002

The AI (H7N2) outbreak in the central Shenandoah Valley in 2002 affected 197 poultry farms and cost US$211 million to eradicate (Bendfeldt *et al.* 2005a,b). Five different methods were used to dispose of AI-infected carcasses: on-farm burial, landfilling, incineration, slaughter and composting. Initially, on-site burial was used but soon stopped as adjoining landowners raised complaints about possible well contamination. About 13,300 t were landfilled (approx 65% of the total), but this proved to be expensive and problematic due to the transport distance and lack of available trucks (Senne *et al.* 2003; Bendfeldt *et al.* 2005a,b). Tipping fees for the carcasses ranged from US$46 to US$90/t, but with euthanasia, transport and tipping fees, the actual disposal cost was US$149/t.

About 43,000 birds (2 flocks) were composted using the Ag-Bag® system and in windrows constructed in the poultry shed. Whilst the in-shed composting method proved to be most successful, Bendfeldt *et al.* (2005b) reported that there were several logistical and technical problems associated with the use of the Ag-Bag® system:

- specialised equipment required permits for transportation and was difficult to move from site to site

- coordination was necessary to provide the necessary supplies, equipment and personnel

- many sites did not have the level ground required to use the system

- careful attention to managing moisture content was needed to prevent excessive moisture content in the finished bags

- uniform mixing of the carcasses and the carbon source was required before loading into the Ag-Bag® and is difficult to achieve

11.3.2. Delmarva Peninsula, 2004

Malone *et al.* (2004) described the success of the use of in-house composting in the AI (H7N2) outbreak on the Delmarva Peninsula of Maryland and Delaware in February 2004. AI was confined to 3 farms despite the high density of poultry farms on the peninsula. The Delmarva poultry industry includes about 2,500 facilities producing approximately 561 million birds per annum. In this operation about 400,000 birds were composted in the sheds and the AI virus was eliminated within 14 days (G. Malone, University of Delaware, pers. comm. 2006). The main features of the operation are outlined below (Malone *et al.* 2004):

- a single 4 m wide windrow was formed in each shed using carcasses, litter and feed. The 1.5 m high windrows were capped with about 7.5 cm of litter or fresh sawdust to cover all exposed carcasses

- the windrows were turned inside the shed, consolidated and capped with additional sawdust at 14 to 19 days into the process

- at 4 to 6 weeks, the compost was removed from the shed, covered and allowed to age on the farm

Additional sawdust was delivered to each farm because the existing litter in each shed (7.5–8 cm) was insufficient for composting. The total available litter on all 3 farms was approximately 1,300 m³ and the additional sawdust required was about 910 m³.

Part of Delmarva's success in containing the outbreak was due to the industry's 'preparedness' (Malone *et al.* 2004). Basic procedural guidelines for in-house composting were available and the disposal team was able to respond within 24 hrs.

Malone *et al.* (2004) also listed some of the challenges faced by the carcass disposal team:

- a lack of a pre-approved list of contractors meeting biosecurity guidelines and who were willing to get involved with the AI outbreak

- it was difficult to find bobcat operators, sawdust suppliers and truck drivers that had limited contact with the poultry industry

- some personnel were concerned about getting involved with the outbreak for fear of repercussions on their business and some were not available on 24-hr notice

11.3.3. British Columbia, 2004

Mixing and piling was the main method used in the highly pathogenic AI outbreak of 2004 in British Columbia. During this outbreak, 1.25 million infected birds were disposed of by burning, burial or composting (Spencer 2005a,b). At the beginning of the outbreak, most carcasses were transported to remote locations where they were burned or buried. Mid-way through the outbreak, the disposal strategy switched to on-farm composting, which in the end disposed of 46% of infected carcasses. The key elements of this operation were as follows (Spencer *et al.* 2005):

- the first stage of composting took place inside the sheds. Composting was initiated as soon as possible after the birds were euthanased with CO_2

- chickens and litter were moistened with water and piled into windrows 2.5 m wide and 1.5 m high. The windrows were covered with wood shavings and were left unturned

- after 5 days the windrows were moved to a new structure outdoors but in close proximity to the sheds (Stage 2). Concrete road barriers were used to contain the structure (Fig. 8, 9). A layer of wood shavings was placed on the ground and heavy black plastic was placed over that. Black 'ag-pipe' was aligned across the plastic at spacings of 1.2 m and protruded out over the concrete barriers to allow for passive aeration (Fig. 8, 9)

- the composting materials from stage 1 were combined with additional wood shavings and placed inside the structure with the aeration pipes at its base. This was covered with 'vapour barrier' (builders sisolation) and then wood shavings and finally black plastic. Aeration vents were placed through the black plastic along the top of the windrow (Fig. 8, 9)
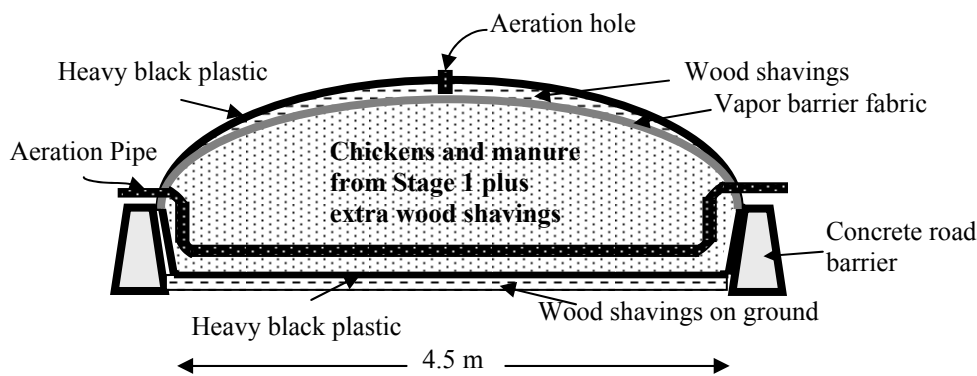

Figure 8: Design of structure used to complete Stage 2 composting in the AI outbreak in British Columbia, 2004 (Spencer *et al.* 2005).

Figure 9: Stage 2 composting in the AI outbreak in British Columbia, 2004 (Spencer *et al.* 2005).

11.3.4. Costs of mass mortality composting

Based on their experience in the Delmarva outbreak, Malone *et al.* (2004) estimated that the total cost of in-shed composting was about 50% less than the alternative option, disposal at local landfills.

E. Bendfeldt, Virginia Cooperative Extension, pers. comm. (2006) provided an estimated cost breakdown of in-shed composting in Virginia for a typical turkey farm shed consisting of 11,400 turkeys of average mass 7 kg. Depending on the scenario, the estimated cost varies from US$11.40 to US$36.37/t of carcass composted (Table 5).

Table 5. Estimated cost breakdown for in-shed composting of turkeys in Virginia. Assumes carcass weight per shed of 80 t. Scenario 1 is the cost breakdown when there is sufficient carbon source already in the shed. Scenario 2 is the case where additional carbon sources need to be delivered to the farm.

Items (per shed)	Scenario 1. Cost (US$)	Scenario 2. Cost (US$)
Bobcats (x2)	280	280
Bobcat operators (@$30/hr)	240	240
Labourers (@$12/hr)	192	192
Compost supervisor	200	200
Hardwood sawdust (@$8/m^3)	-	1,800
Sub-total	912	2,190
Cost per tonne of carcass	11.40	27.37
Additional cost when no litter storage shed is available		
Compost fleece[1]	720	720
Total	1,632	2,910
Cost per tonne of carcass	20.40	36.37

[1]One 60 m roll of reusable compost cover per shed

11.4. Mass mortality composting in other industries

The use of mass mortality composting as the main method of carcass disposal in an EAD outbreak is probably only likely for small to medium sized carcasses. It works particularly well in the broiler industry because of the on-site availability of co-composting material (ie litter) and the possibility of conducting the composting inside the shed itself.

Nevertheless, the experience of the FMD outbreak in Great Britain in 2001 has increased the prospect that composting could play a limited role in any future large animal EAD outbreak. With this in mind, Glanville (undated) has developed draft guidelines for emergency composting of large animal carcasses. These guidelines suggest the use of a 60 cm base layer and a cover of between 90 and 120 cm above each pair of animals (Fig. 10). Each pair of animals requires a windrow about 2.5 m

in length. Glanville points out that large animals require large quantities of base and cover materials. About 10 m^3 of C source is needed for each 450 kg carcass composted. He advises that beef or dairy operations considering using composting for emergency disposal to stockpile cover materials as part of their emergency response plan. As a guide, a 100 animal composting operation according to Fig. 10 would require about 100 t of ground hay or straw (200 large round bales), 142 t of ground cornstalks (280 large round bales), or 325 t of corn silage as base and cover materials.
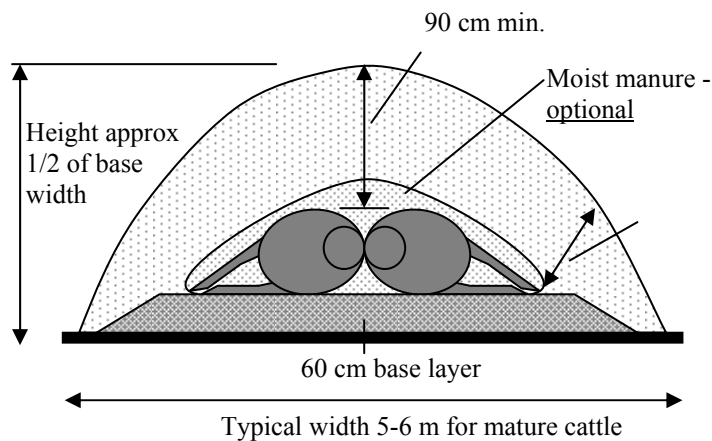

Figure 10: Layout of piles for emergency composting of cattle carcasses (Glanville undated).

12.   Conclusions

12.1.   General comments

On-farm mortality composting is likely to play an increasing role in carcass disposal due to a general contraction in the availability of rendering services and tightening regulations governing on-farm burial. It is a relatively simple and effective process and, if done properly, it appears to meet the biosecurity, environmental, and public health objectives of safe carcass disposal. It can be used successfully for the routine management of farm animal mortalities of all sizes. Mortality composting is particularly suited to the broiler industry for management of mass mortalities in the event of an EAD outbreak.

12.2.   Development of strategies to increase adoption

To facilitate more widespread adoption of mortality composting, it is critical to investigate mortality disposal in Australia, identify drivers for change and barriers to adoption. This approach needs to consider the whole business context in particular industries because the barriers to adoption of mortality composting may come from both internal (e.g. lack of awareness or cost) and external sources (e.g. local government planning permits).

Farmers often have sound, logical reasons for not adopting a given practice. Lack of awareness, unsatisfactory access to information or inadequate learning skills may not be the all-pervasive barriers to adoption we sometimes think them to be (Kaine *et al.* 2005). Extension programs can be ineffective if they are based solely on the assumptions of research and extension officers about what an industry 'needs'. These assumptions are often based on the 'needs' or agenda of government rather than the industry itself (Kaine *et al.* 2005). The solution to this problem is in seeking a better understanding of the whole business context of particular industries and to use the appropriate adoption strategies targeted at groups of farmers with the capacity to change.

An adoption strategy for mortality composting might include training programs. Training of personnel was shown to be of critical importance to the successful operation of mass mortality composting in the Delmarva AI outbreak of 2004 (Malone *et al.* 2004). Successful training programs on the use of composting for the routine management of mortalities has also proven to be successful in Ohio (Keener *et al.* 2005). Ohio State University has trained over 2,900 Ohio farmers in mortality composting since 1995. Follow-up surveys of trained livestock producers revealed a high degree of satisfaction (>90% of respondents) in the skills learnt during the program and the success of their on-farm composting operations.

12.3. Research and development gaps

Most of the available literature on mortality composting has concentrated on the general principles and operation of the process. Though the use of composting to manage mass mortalities shows great promise, the relative paucity of peer reviewed science in this field needs to be addressed.

Very few studies have examined the biosecurity and environmental impacts of mortality composting, either in the context of routine management of mortalities, or for catastrophic losses.

To the author's knowledge, a risk assessment of mortality composting has not yet been published, nor are any such studies currently under-way. Modelling techniques could be used to quantify the risks to animal and public health from the spread of particular diseases from mortality composting operations. Gale (2002) successfully used this approach to develop recommendations for the composting of catering waste containing meat. He showed that the quantity of material that bypasses the composting process is of critical importance to the overall level of risk. Material bypass could be even more critical for mortality composting given the heterogenous nature of the pile.

Despite its importance from a biosecurity perspective, very few studies have been conducted on the inactivation of pathogens in mortality composting. The pathogen reduction credentials of mortality composting have largely been derived from conventional composting systems. Nevertheless, many researchers have also highlighted the differences between conventional and mortality composting systems. These usually relate to the heterogenous pile conditions, minimal process management and relatively long time frames of mortality composting compared to conventional composting. As stated in this review, it is possible to gain a high degree of confidence that the whole mass of composting material has reached a given time-temperature treatment in any composting system, provided that temperature profiles

are known. To do this, mortality composting studies need to show spatial and temporal changes in temperature profiles within a heap.

12.4. *Potential use of mass mortality composting*

Mortality composting is particularly suited to the broiler industry for both routine and emergency management of mortalities for the following reasons:

- the availability on-farm of co-composting materials in the form of poultry litter

- on its own, or in combination with mortalities, poultry litter is an ideal substrate for composting. High temperatures are readily achieved in poultry litter piles without the need for high levels of process management

- compared to larger animals, birds break down very quickly (10–14 days as opposed to many months for others)

In the case of an EAD outbreak, composting can be conducted effectively inside the poultry shed. This has the demonstrated advantage of containing and limiting the spread of the outbreak.

The lack of SOPs for mortality composting was identified by both Australian and international biosecurity agencies as a major impediment to the use of on-farm composting in any future EAD outbreak (DAFF 2005). An extensive search of the literature and consultations with both Australian and international experts identified many extension type publications but no published SOPs on mortality composting. One draft SOP for mass poultry mortality composting has been identified from NSW DPI.

The study identified several publications that would assist the drafting of SOPs, but it has also shown that further work is needed to fully evaluate the biosecurity credentials of mortality composting, particularly in the context of an EAD outbreak. Thus SOPs must be underpinned by sound science.

The demonstration of in-shed composting is a critical part of any plan to prepare industry for an EAD outbreak like AI in Australia (M. McKenzie, Inghams Enterprises, pers. comm. 2006). This has also been the experience of those involved in AI outbreaks in North America (G. Malone, University of Delaware, pers. comm. 2006). This type of hands-on experience is important to ensure that SOPs are relevant and can be effectively implemented in the event of emergency. The logistics of carcass disposal are critical for the successful implementation of the operation. It could be argued for example, that the logistics of the British Columbia AI composting operation were overly complicated by the use of concrete road barriers in the second phase of composting (Fig. 8, 9). This probably reflects the fact that SOPs have not been developed in Canada and the personnel involved had little direct hands-on experience with mass mortality composting.

13.   Recommendations

The following recommendations have emerged as a result of this literature review:

- effective and targeted strategies must be developed to overcome barriers to adoption of mortality composting in key industries. These strategies need to be

underpinned by a sound understanding of the full business context of intensive animals industries in order to identify their drivers and capacity for change

- the implications of the use of mortality composting on biosecurity need further investigation. Pathogen inactivation and risk assessment modelling studies are required to identify critical pathways for the spread of pathogens, quantify risks and to assist in the development of SOPs

- studies are needed on the environmental impact of mortality composting. Perception about the negative environmental impact of mortality composting may limit its widespread adoption

- SOPs need to be developed for mortality composting, especially in the context of emergency carcass disposal. These SOPs need to be demonstrated to industry

- an investigation is needed on the use of composting to manage an EAD outbreak in the Australian poultry industry. The investigation should consider the economic, technical and logistical feasibility of the use of composting. Various approaches to composting need to be evaluated from a biosecurity, public health and environmental perspective

14.   Acknowledgments

15.   References

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